Antimicrobial Efficacy of External Fixator Pins Coated with a Lipid Stabilized Hydroxyapatite/Chlorhexidine Complex to Prevent Pin Tract Infection in a Goat Model

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Background: **Pin tract infection is a common complication of external fixation. An antiinfective external fixator pin might help to reduce the incidence of pin tract infection and improve pin fixation.**

Methods: **Stainless steel and titanium external fixator pins, with and without a lipid stabilized hydroxyapatite/chlorhexidine coating, were evaluated in a goat model. Two pins contaminated with an identifiable *Staphylococcus aureus* strain were inserted into each tibia of 12 goats. The pin sites were examined daily. On day 14, the animals were killed, and the pin tips cultured. Insertion and extraction torques were measured.**

Results: **Infection developed in 100% of uncoated pins, whereas coated pins demonstrated 4.2% infected, 12.5% colonized, and the remainder, 83.3%, had no growth ($p < 0.01$). Pin coating decreased the percent loss of fixation torque over uncoated pins ($p = 0.04$).**

Conclusion: **These results demonstrate that the lipid stabilized hydroxyapatite/chlorhexidine coating was successful in decreasing infection and improving fixation of external fixator pins.**

Key Words: **External fixation, Pin, Infection, Hydroxyapatite, Chlorhexidine.**

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Pin tract infection is an unfortunate but common complication of external fixation. Rates of pin tract infection vary widely in the literature. Major pin tract infection, defined as requiring hospital admission for parenteral antibiotic therapy, pin removal, or fixator removal, averages 5.8%.[1] Overall rates of pin tract infection, to include less severe infections, have been reported as high as 100%.[1] It is unclear whether loosening and separation precede or follow the onset of pin sepsis. In either case, however, infected pin sites are associated with pin loosening, fracture destabilization, and osteomyelitis.[2]

An additional problem arising from pin tract infection is the risk of infection when converting external fixation to internal fixation. The incidence of deep infection after the conversion of external fixation to intramedullary nailing of the tibia has been reported at up to 71% when performed after there has been evidence of a pin site infection.[3,4] This is in contrast to a 5.9% deep infection rate when converting external fixation to intramedullary nailing in the absence of pin site infection.[3] Additional studies support low rates of deep infection, from 0% to 5.9%, resulting from intramedullary nailing after external fixation when pin tract infection was absent or adequately treated.[5–7]

In an effort to decrease pin tract infection while maintaining pin stability, a unique pin coating was conceived and developed in a cooperative research agreement. This coating combines hydroxyapatite, with its ability to improve the interface between bone and metal implants, and chlorhexidine, with its low toxicity and broad antimicrobial activity.[8] This process has been refined to increase the amount of chlorhexidine applied to the pin, and incorporates a lipid coating to slow the elution of the chlorhexidine. The purpose of the study was to evaluate the ability of this lipid stabilized hydroxyapatite/chlorhexidine coating to reduce the incidence of pin tract infection and improve pin fixation in a goat model.

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MATERIALS AND METHODS

Pin Coating

The pin coating is applied through a multiple layering process of hydroxyapatite and chlorhexidine. A surface-induced mineralization technique was used to produce a hydroxyapatite coating on the external fixator pins. Chlorhexidine was then incorporated into the coating by placing the hydroxyapatite-coated pin into a chlorhexidine solution.[8] This process of hydroxyapatite mineralization followed by chlorhexidine addition was repeated at least four times until the coating was of the desired thickness (6–10 μm). To slow the release of the chlorhexidine from the coating, a lipid

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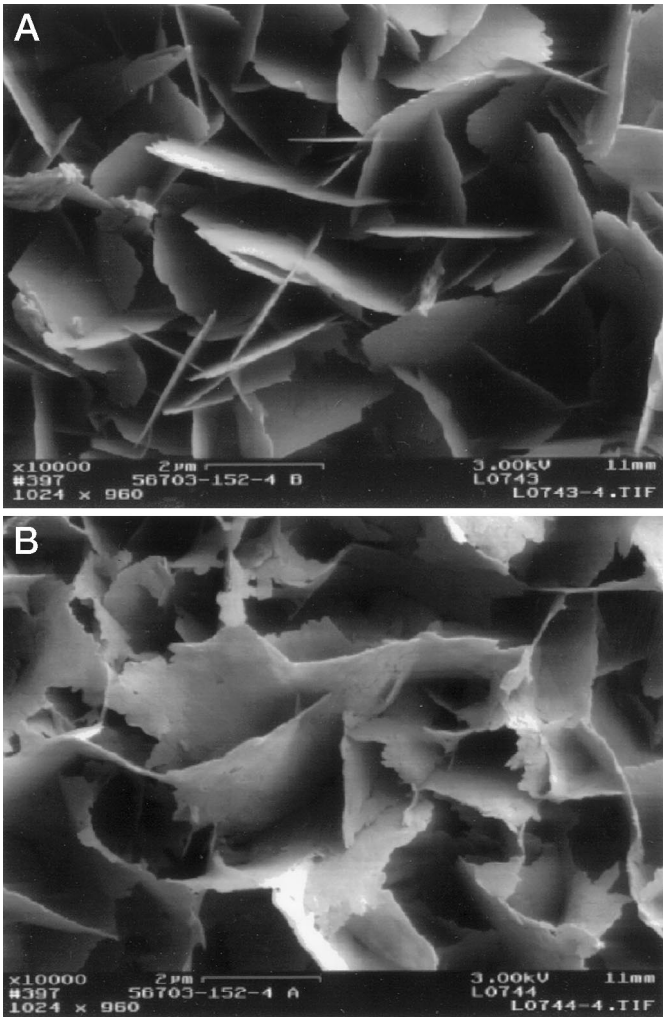

Fig. 1. *(*A*) Scanning electron micrograph of hydroxyapatite coating after the incorporation of chlorhexidine. (*B*) Scanning electron microscopic image of hydroxyapatite/chlorhexidine coating after soaking for 48 hours in saline solution.*

overlayer was applied to the coated pins. The lipid creates a biocompatible layer over the coating that slowly dissolves, slowing the release of the chlorhexidine.

The pin coating was evaluated using scanning electron microscopy to ensure the durability of the hydroxyapatite coating both after the addition of chlorhexidine and after release of the chlorhexidine in a saline bath. Figure 1*A* shows a typical appearance of the coating with chlorhexidine incorporated. There were no indications that the incorporation of chlorhexidine causes the dissolution of the hydroxyapatite coating or alteration of the phase of the mineral deposited. Figure 1*B* shows the coating after soaking in a saline bath for 48 hours. The coating exhibits only a small fraction of dissolution demonstrated by the roughened edges of the hydroxyapatite crystals. It is important that the release of the chlorhexidine not be because of the complete dissolution of the hydroxyapatite coating, since the hydroxyapatite enhances pin fixation.

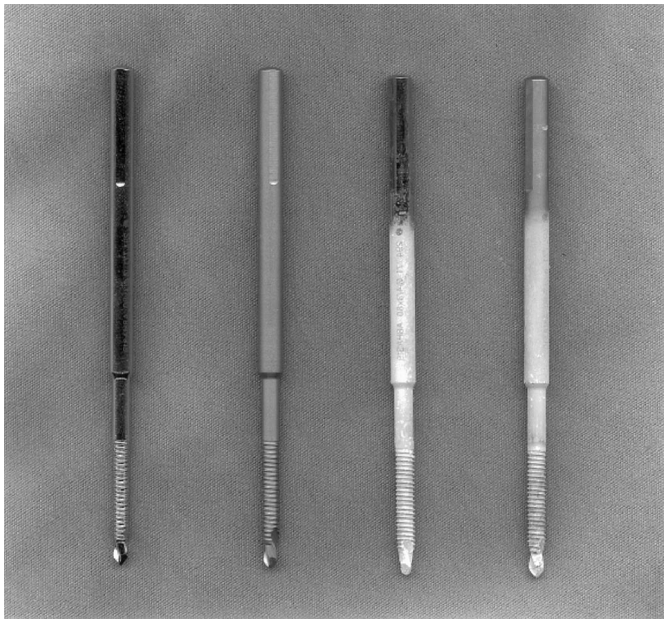

Fig. 2. *External fixator pins from left to right: uncoated stainless steel, uncoated titanium, coated stainless steel, and coated titanium.*

Experimental Methods

The experimental protocol used for this work was evaluated and approved by the Institutional Review Board and the Institutional Animal Care and Use Committee. Animals were obtained from a single licensed vendor and maintained in a secure, climate-controlled facility for the duration of the experimental protocol. Adherence to established guidelines for the treatment of animal subjects was strictly maintained.

Twelve mature castrated male Spanish goats were used for this study. Veterinary staff evaluated the animals initially and observed them for 1 week to exclude the possibility of preexisting disease or untreated parasitic condition. The animals were fasted for 48 hours before surgery. Preoperatively, the animals were sedated, then anesthetized with general endotracheal anesthesia. Epidural morphine sulfate (Duramorph, 0.1 mg/kg) was administered via spinal needle as an epidural analgesic for perioperative and postoperative pain management.

The hindlimbs of each animal were prepared using a chlorhexidine scrub. Incisions 2.5 cm in length were made in the medial aspect of both hindlimbs, the first placed 3 cm above the ankle joint and the second placed 10 cm above the first. The incisions were made on the subcutaneous border of the tibia. Hemostasis was maintained with electrocautery. The periosteum was incised and retracted. The proper 3.0/4.0-mm external fixator pin (Synthes, Monument, CO) was inserted into the medial tibial face with the use of a power drill. Each animal received one of each of the following external fixator pins (Fig. 2): an uncoated stainless steel pin, an uncoated titanium pin, a lipid stabilized hydroxyapatite/

chlorhexidine coated stainless steel pin, or a lipid stabilized hydroxyapatite/chlorhexidine coated titanium pin.

The assignment of pin type to pin site was balanced so that each pin type was represented equally at each pin site location. Each pin was inoculated with 30 μL of a 10^6 colony forming units (CFU)/mL solution of *Staphylococcus aureus* (ATCC 29213), applied to the pin threads, before final insertion. This bacterium has been genetically selected to be resistant to streptomycin to facilitate bacterial identification. The pin insertion was completed by hand so as to confirm adequate placement through the far cortex of the tibia. Torque measurements were taken with final insertion (BGI Remote Sensor, STE200 torque wrench extension, Mark-10 Corporation, Hicksville, NY) by the first author (E.S.D.) in all measurements. After placement of the pins, the wounds were left open and sterilely dressed with pin dressing sponges (Smith & Nephew, Inc., Memphis, TN) and sponge clips. The pins were cut short, approximately 2 cm above the sponge, and pin caps were applied to the cut pin ends. Gauze roll and a stockinette were then applied. Each goat was then extubated and allowed to recover in its cage under the direct supervision of a veterinarian technician.

Daily evaluations of each pin site by three independent observers began after an initial incubation period of 48 hours after surgery. The dressings were carefully changed to avoid cross-contamination of the pin sites. The condition of the pin was annotated individually by each observer as one of the following: no infection, inflammation or serous drainage without frank purulence, or frank purulence at the pin site. The clinical determination of infection was defined as all three observers agreeing that purulent drainage was present at a given pin site on any one day during the clinical evaluation period. After evaluation, the pins were superficially wiped clean with a dry sterile gauze, new pin dressing sponges were applied to the pin sites, the pin sites were overwrapped to avoid cross-contamination, and the animals were returned to their individual pens.

On postoperative day 14, the animals were killed. Each pin site was assessed for purulent drainage and scored according to the criteria listed above. Next, the soft tissue was carefully stripped from around each pin in preparation for pin removal. Extraction torque was measured for each pin by the first author. Each pin was then removed, and the terminal 10 mm of the pins were sterilely cut and placed into phosphate-buffered saline with 0.01% trypsin. The pin tips were vortexed for 30 seconds, then sonicated for 3 minutes to remove the bacteria from the tip. Quantitative bacterial counts were performed by the spread plate method on trypticase soy agar.[9] Isolation and identification of the bacterial species was performed on MacConkey agar plates and trypticase soy agar plates with 5% sheep blood. Isolates were identified by routine mirobiologic procedures. Each *S. aureus* isolate was tested for streptomycin resistance to assess if it was the same streptomycin-resistant strain as that from the initial pin inoculation.

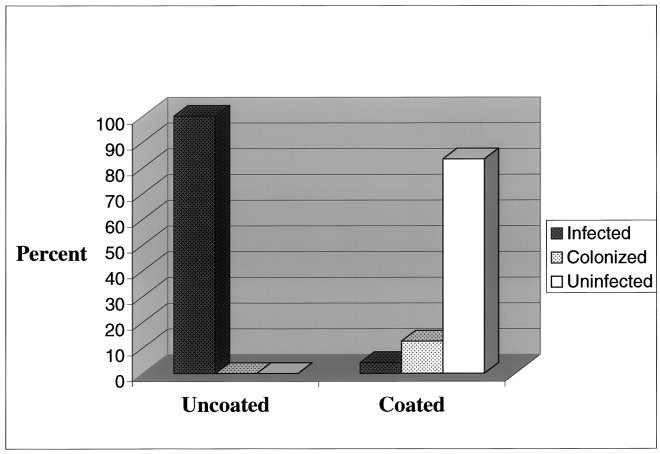

Fig. 3. *Percent infection by pin tip culture.*

Data Analysis

Torque data were analyzed by analysis of variance. CFU data were analyzed by Mann-Whitney *U* test. Means ± SEM are reported for torque data. Discrete data, such as true infection rate, were analyzed by χ^2. Statistical significance was determined by $p < 0.05$. All data were analyzed using SAS statistical software (SAS Institute, Cary, NC, 1989).

RESULTS

Evaluation of the quantitative culture results from the 10-mm tip of the pins revealed that the uncoated pins developed infection from the test strain in all 24 pins (100%), with an average total colony count from the pin tip of 3.2×10^6 (8.5×10^4 to 9.1×10^6) CFU (CFU per milliliter pin isolate solution multiplied by volume of solution). The coated pins demonstrated no growth in 20 of 24 pins (83.3%), colonization in 3 of 24 pins (12.5%) with average total colony counts of 2,500 CFU (1,500–3,500) per pin tip, and infection in one pin (4.2%), demonstrating 3.3×10^4 CFU (Fig. 3). This difference in infection rates between coated and uncoated pins was significant ($p < 0.001$). No effect of metal type or pin location was found in evaluating culture results.

Clinical evaluations revealed purulence around 23 of 24 uncoated pins (95.8%), whereas only 5 of 24 coated pins (20.8%) developed purulence ($p < 0.01$) (Fig. 4). No difference in rates of pin purulence between metals was found. Combining clinical and microbiologic data, criteria for "confirmed infection" were established. These criteria state that a diagnosis of "confirmed infection" requires both the appearance of clinical infection and positive microbiologic culture with colony counts of 10^4 CFU/pin tip or greater. Using these criteria, the uncoated pins developed confirmed infection from the test strain in 95.8% (23 of 24) of the cases, whereas the coated pins had no infections ($p < 0.01$) (Fig. 4).

Evaluating pin fixation torque data, it was found that all pins had a reduction in fixation torque from insertion to extraction. However, combining metals, pin coating decreased the percent loss of fixation torque compared with

Coated Pins

Pin Type	Goat #	Clinical	Pin Tip Org.	CFU	Confirmed Infection
Coated Ti	111	Pos	no growth	0	no
Coated Ti	109	Neg	no growth	0	no
Coated Ti	118	Pos	no growth	0	no
Coated Ti	121	Neg	no growth	0	no
Coated Ti	105	Neg	*Coag. Neg Staph*	3500	no
Coated Ti	122	Pos	*S. aureus*	2500	no
Coated Ti	124	Neg	no growth	0	no
Coated Ti	136	Neg	no growth	0	no
Coated Ti	137	Neg	no growth	0	no
Coated Ti	129	Neg	no growth	0	no
Coated Ti	146	Neg	no growth	0	no
Coated Ti	133	Neg	no growth	0	no

Pin Type	Goat #	Clinical	Pin Tip Org.	CFU	Confirmed Infection
Coated SS	111	Neg	no growth	0	no
Coated SS	109	Neg	no growth	0	no
Coated SS	118	Pos	no growth	0	no
Coated SS	121	Neg	*Coag. Neg Staph*	33000	no
Coated SS	105	Pos	*S. aureus*	1500	no
Coated SS	122	Neg	no growth	0	no
Coated SS	124	Neg	no growth	0	no
Coated SS	136	Neg	no growth	0	no
Coated SS	137	Neg	no growth	0	no
Coated SS	129	Neg	no growth	0	no
Coated SS	146	Neg	no growth	0	no
Coated SS	133	Neg	no growth	0	no

Uncoated Pins

Pin Type	Goat #	Clinical	Pin Tip Org.	CFU	Confirmed Infection
Uncoated Ti	111	Pos	*S. aureus*	3,800,000	yes
Uncoated Ti	109	Pos	*S. aureus*	4,200,000	yes
Uncoated Ti	118	Pos	*S. aureus*	1,700,000	yes
Uncoated Ti	121	Pos	*S. aureus*	2,200,000	yes
Uncoated Ti	105	Pos	*S. aureus*	400,000	yes
Uncoated Ti	122	Pos	*S. aureus*	850,000	yes
Uncoated Ti	124	Pos	*S. aureus*	84,500	yes
Uncoated Ti	136	Neg	*S. aureus*	960,000	no
Uncoated Ti	137	Pos	*S. aureus*	3,450,000	yes
Uncoated Ti	129	Pos	*S. aureus*	9,050,000	yes
Uncoated Ti	146	Pos	*S. aureus*	6,450,000	yes
Uncoated Ti	133	Pos	*S. aureus*	1,240,000	yes

Pin Type	Goat #	Clinical	Pin Tip Org.	CFU	Confirmed Infection
Uncoated SS	111	Pos	*S. aureus*	1,800,000	yes
Uncoated SS	109	Pos	*S. aureus*	2,200,000	yes
Uncoated SS	118	Pos	*S. aureus*	700,000	yes
Uncoated SS	121	Pos	*S. aureus*	3,950,000	yes
Uncoated SS	105	Pos	*S. aureus*	6,050,000	yes
Uncoated SS	122	Pos	*S. aureus*	2,700,000	yes
Uncoated SS	124	Pos	*S. aureus*	650,000	yes
Uncoated SS	136	Pos	*S. aureus*	7,150,000	yes
Uncoated SS	137	Pos	*S. aureus*	2,050,000	yes
Uncoated SS	129	Pos	*S. aureus*	3,850,000	yes
Uncoated SS	146	Pos	*S. aureus*	4,700,000	yes
Uncoated SS	133	Pos	*S. aureus*	3,750,000	yes

Fig. 4. *Pin listing by pin type with clinical microbiologic (14 days after insertion), and combined infection data listed. "Clinical" refers to purulent drainage at pin site during daily dressing changes. "Confirmed Infection" requires clinical purulence and positive microbiologic cultures.* Light shading *indicates colonized,* dark shading *indicates infection.*

uncoated pins ($p = 0.04$) (Table 1). Furthermore, titanium pins were found to retain fixation strength better than stainless steel pins ($p < 0.01$).

DISCUSSION

Different methods have been used to improve the interface between external fixator pins and bone. Titanium coating of stainless steel pins was shown to result in greater extraction torques than uncoated stainless steel pins, after implantation in a sheep model for 6 weeks.[10] Other studies have shown that hydroxyapatite improves the bone-pin interface when coated onto external fixator pins.[10–15] Hydroxyapatite coating has resulted in improved fixation of external fixator pins in both animal models and human clinical trials. In one human clinical study, hydroxyapatite-coated and uncoated stainless steel pins were compared. The authors found improved removal torque and a decreased incidence of pin tract infection in the hydroxyapatite-coated pins, leading the authors to conclude that improved pin stability was responsible for the decrease in pin tract infection.[12]

In addition to improving stability of external fixator pins, our goal was to develop a pin that would actively resist infection. Hydroxyapatite ceramics have been used as a delivery system for antibiotics.[16,17] A hydroxyapatite-coated pin could thus potentially improve fixation and deliver an anti-infective compound to actively resist infection. Anti-infective techniques for external fixator pins used in the past include the use of tobramycin-impregnated sleeves that fit over pins. These were tested in a goat model, and effectively eliminated induced infection.[18] However, the environment of an external fixator pin exposes the pin constantly to bacterial pathogens. Using an antibiotic, under such circumstances, might lead to resistant pathogens, defeating the pin's purpose and possibly creating more resistant, difficult-to-treat organisms.[19]

A disinfectant, with a lower chance of resistance development than an antibiotic, may be a better solution to reducing pin tract infection. Silver-coating of external fixator pins to decrease pin tract infection has been used in the past; however, studies demonstrate little[20] or no improvement[21] in

Table 1 **Insertion and Removal Torque Presented as Mean ± SE**

	Uncoated Stainless Steel	Coated Stainless Steel	Uncoated Titanium	Coated Titanium
Insertion torque (in-lb)	18.0 ± 1.2	16.0 ± 1.2	13.6 ± 1.2	15.9 ± 1.2
Removal torque (in-lb)	8.4 ± 0.8	9.1 ± 0.8	8.6 ± 0.8	10.4 ± 0.8
Change in torque (in-lb)	–9.6 ± 0.6[a]	–6.9 ± 0.6[a]	–5.0 ± 0.6[a]	–5.5 ± 0.6[a]
Percent change in torque	–54.8 ± 2.8[a,b]	–44.6 ± 2.8[a,b]	–35.8 ± 2.8[a,b]	–34.0 ± 2.8[a,b]

[a] Titanium pins had decreased loss of fixation torque and decreased percent change of fixation torque vs. stainless steel pins ($p < 0.01$).
[b] Coated pins had decreased percent change of fixation torque vs. uncoated pins ($p = 0.04$).

infection rates over uncoated stainless steel pins. Chlorhexidine is a commonly used disinfectant for hand washing and site preparation for surgical procedures. This disinfectant provides a high level of antibacterial activity with low levels of resistance.[19,22–24] Concentrations of chlorhexidine required for bacterial inhibition are low, with concentrations of 10 to 50 μg/mL required for inhibition of most bacterial species.[22,24] Furthermore, low levels of bacterial resistance to chlorhexidine are maintained, even during prolonged use.[19,23] Its mechanism of action combines the rapid bactericidal action of iodophors (which lack persistence) with the persistent action of hexachlorophene.[22]

Chlorhexidine has been found to have low toxicity. Extensive testing has been performed with both topical application of chlorhexidine over prolonged periods[22] and internal use of chlorhexidine, to include chlorhexidine-coated intravenous catheters,[19] chlorhexidine-impregnated surgical mesh,[25] and chlorhexidine-containing irrigation for chronic peritoneal dialysis,[26] without significant toxicity. As a result of this low level of toxicity, chlorhexidine has Food and Drug Administration approval for human use when applied to internally placed medical devices, to include intravenous catheters and implanted antimicrobial surgical mesh.[27]

In this study, we demonstrated that with bacterial contamination of external fixator pins, infection from the inoculated strain of bacteria, as demonstrated by microbiologic cultures, developed in all uncoated pins. This demonstrates that in the absence of treatment, the experimentally induced infection will develop. In contrast, the hydroxyapatite/chlorhexidine coating reduced the rate of infection and the severity of the infection in those pins that developed infection ($p < 0.001$). This suggests that the hydroxyapatite/chlorhexidine coating was highly effective in reducing the incidence and severity of pin tract infection in this experimental model.

Our method of external fixator pin contamination, a direct inoculation of the pin with bacteria during insertion, does not mirror how an external fixation pin would be infected clinically. However, our model does offer a reproducible bacterial inoculum to the pin, allowing a highly reproducible pin tract infection in untreated pins. In an experimental model, a highly reproducible pin tract infection is desirable, as it allows for the evaluation of anti-infective treatments with a minimum number of animals. Without this inoculation of bacteria to the pins, the degree of contamination of each pin would be left to chance, substantially increasing the variability in the development of pin tract infection, thus greatly increasing the number of animals needed to evaluate an anti-infective pin treatment.

During the daily pin evaluations, we noted that a few coated external fixator pins developed a clinical infection by our criteria, yet the pin tips were sterile at the termination of the study period (Fig. 4). We hypothesize that this is the result of our establishing a soft tissue infection around the pin, which subsequently cleared, leaving the pin itself sterile. During insertion of the pin, a generous incision of approximately 2.5 cm was made. This was done to avoid tenting or tethering of the skin on the animal's leg, which occurs during flexion and extension of the limb as a result of the high mobility of the goat's skin in this area. During application of the *S. aureus* to the pin, which was performed when each pin was partially inserted, a portion of the inoculum of *S. aureus* may have run into the soft tissues around the pin. In this relatively large wound, it appears from our daily observations that we established a soft tissue infection at the pin site of the coated pins in some of the animals. Despite establishing this peripheral soft tissue infection, which would have certainly resulted in a constant exposure of the pin to the inoculated bacteria over a prolonged period, the coated pins themselves remained uninfected in the vast majority of cases. Thus, the pins were able to resist infection in the bone-pin interface not only from the initial contamination of the pin with *S. aureus*, but also from a prolonged exposure to an infective organism.

Evaluation of our pin fixation torque data revealed that all pins had a reduction in fixation torque from insertion to extraction. When comparing groups of pins, however, pin coating was noted to decrease the percent loss of fixation torque as compared with uncoated pins. Furthermore, titanium pins, when considered together, were found to retain fixation strength better than stainless steel pins. These findings are congruent with other studies, which suggest that both titanium coating[10] and hydroxyapatite coating[10–15] can improve fixation as compared with uncoated stainless steel pins. The duration of our experimental protocol is fairly short, however, and prolonged implantation may be necessary to fully delineate differences in fixation torque of these pin and pin coating combinations.

CONCLUSION

In conclusion, we found that the lipid stabilized hydroxyapatite/chlorhexidine coating was successful in decreasing the incidence of pin tract infection as compared with uncoated pins in our in vivo goat model. The coated pins demonstrated a decreased percent loss of fixation torque as compared with uncoated pins. Finally, titanium pins were found to retain fixation strength better than stainless steel pins.

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DISCUSSION

Dr. Bruce D. Browner (Hartford, Connecticut): Dr. Maull, Dr. Shackford, members, and guests, thank you for the opportunity to discuss this article. Over the past decade, mandatory seat belt use, drunk-driving control, airbags, and improved car design have reduced the number of complex open fractures, the major arena for external fixation.

Reliance on this technique has been further deemphasized by the growing use of locked unreamed intramedullary nailing and minimally invasive plating. Automobile-pedestrian encounters and motorcycles, however, continue to produce complex upper and lower extremity injuries that require external fixation.

It is still used for extended periods in posttraumatic reconstruction and the treatment of chronic osteomyelitis. As all patients know who have had the device on their limbs or pelvis, pin tract infection is an enemy. They fight a constant border war living with discomfort and pain, cleaning their pin sites, and remain anxious over increases in swelling, redness, and drainage, which could signify a major invasion.

The orthopedist must be vigilant as well, following the pin tracts radiographically to detect periosteal new bone formation and lysis, which confirm an incursion of infecting organisms into bone. A surgical strike is often necessary to curette dead bone from the pin tract and replace prematurely loosened pins. In a worst-case scenario, infection can contaminate the fracture site, bone graft, or subsequent intramedullary nailing.

As an old warrior who has struggled through many of these battles, I would welcome a new defensive weapon. For this reason, I was intrigued with the device described by these authors: a hydroxyapatite-coated pin that can slowly release chlorhexidine through a superficial stabilizing layer of lipid. In the experimental model used, these results are impressive. I have a number of concerns that would have to be addressed before I could recommend widespread adoption of this device for military and civilian use, and I'll go over them.

In this study, the infecting organisms were introduced by dipping the pin tips in bacterial cultures before insertion. In the clinical setting, the infection generally begins in the soft tissue pin tract wound, extending in a small percentage of cases down into the bony pin tract.

In a subsequent study, it would be interesting to see the infection-suppressing capability of these pins if the bacteria were introduced into the overlying soft-tissue wound after pin insertion.

Pin loosening results from a variety of factors including mechanical loading, the reaction of bone to different materials in the pin, and infection. Aseptic loosening of pins from the first two factors can set the stage for subsequent infection.

A more convincing analysis of the resistance of different pins to mechanical loosening and infection could be accomplished in a subsequent study that should use osteotomy of the goat's tibia and a standardized blunt injury to the hindlimb instead of using the intact tibia as was done in this study. The osteotomy should be stabilized, then, by insertion of the same type of pins, coated and uncoated, with the releasing capability that could then be connected together by a standard external fixator.

The 2 weeks between when the pins are inserted and when the animals are killed should be extended to 6 to 8 weeks to allow a more clinically relevant period of loading and a greater opportunity for pin loosening that could then lead to subsequent infection.

As the authors have noted, other investigators have reported reduced loosening rates and less pin infection with hydroxyapatite coating alone. For this reason, subsequent studies should include a group of pins that have hydroxyapatite coating alone without the chlorhexidine-releasing capability.

The ability of chlorhexidine to eradicate *S. aureus* in this study was quite impressive. Its broad-spectrum bactericidal capability and low toxicity would make it a good substance to incorporate into external fixation pin tract dressings.

It would be interesting to see a separate study in which the bony pin tract infection rates and loosening were studied after overlying pin tract wounds were treated with and without chlorhexidine-containing dressings. Extensive studies on the biocompatibility of chlorhexidine have convinced the Food and Drug Administration to make it available in the coatings of catheters and surgical mesh. However, they may not yet have addressed the possible adverse effects of this substance on bone formation.

After removal of external fixator pins, the pin hole is the site of weakness in the bone. This is strengthened by the formation of new bone in the periphery of the pin hole.

Some of the animals in a subsequent study would have to be kept alive for an additional 6 weeks after pin removal to determine whether or not the restrengthening bone formation had occurred in the pin holes after the use of hydroxyapatite-chlorhexidine releasing pins.

In closing, I would like to commend Dr. Brad Nelson and Dr. Allison Campbell for the invention of this device and congratulate Major DeJong and his coauthors for their exciting study.

I hope that they will regard my criticisms as constructive and urge them to continue their studies in this important area. Thank you, again, for the privilege of discussing this study.

MAJ E. Schuyler DeJong (closing): Thank you very much for your comments. You brought up some very good points for us to consider in the future.